

A STUDY ON MANUFACTURING LIGHTWEIGHT COMPOSITE METAL FOAM FOR HIGHER ENERGY ABSORPTION APPLICATIONS

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COMPOSITE METAL FOAM FOR HIGHER ENERGY
ABSORPTION APPLICATIONS**

by

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Submitted

**in fulfillment of the requirement of the degree of Doctor of
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CERTIFICATE

This is to certify that the thesis entitled “**A Study on Manufacturing of Lightweight and Stiff Composite Metal Foam for Higher Energy Absorption Applications**” being submitted by Mr. Fisseha Zewdie to the Indian institute of technology Delhi for the award of the degree of Doctor of Philosophy in Mechanical Engineering is a record of original and Bonafide research work carried out by him under my supervision and guidance. The thesis work, in my opinion, has reached the requisite standard for the degree of Doctor of Philosophy.

The results contained in this thesis have not been submitted, in partial or in full, to any other university or institute for the award of any degree or diploma.

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ABSTRACT

Metal foam is a synthetic cellular material being used for various commercial and military applications. For instance, Titanium and Magnesium foams serve as bone implants due to their biocompatibility. On the other side, Aluminum foam can be applicable for building wall construction, sound, shock or vibration damping, thermal insulation, heat exchangers, automotive body parts, collision/crush protection. Additionally, military products such as blast mitigation and ballistic protection applications. While steel foams were studied for ballistic protection applications, the common metal foams currently in use for blast mitigation and collision protection are aluminum foams due to their high strength-to-weight ratio and corrosion resistance. However, the limitation associated with the aluminum and steel foams produced using foaming agents like TiH_2 powder was their low strength-to-weight ratio, which was unable to meet the current requirement of higher energy absorption capability. For this, researchers tried to use space holders to create pores in the aluminum matrix. One of the recently conducted studies used stainless steel hollow spheres (SHS) and ceramic hollow spheres as reinforcement in the aluminum matrix to improve the compressive strength of the foam. Further, in another study, the ceramic hollow spheres were layered with a steel powder layer, sintered at the sintering temperature of the steel and used as reinforcement to improve the compressive strength and deformation strain of the aluminum matrix foam and hence had higher energy absorption capacity compared to the aluminum foam. However, these foams still have inferior mechanical properties. A new study was needed to enhance compressive strength, porosity and deformation strain since these parameters are directly related to the higher energy absorption property. Therefore, the matrix material should be changed from aluminum to aluminum-alloy, similarly the properties of the ceramic and steel hollow spheres need to be improved for higher performance of the closed-cell foam.

Generally, by controlling the properties of the input materials, the main properties of the metal foam, such as its lightweight, high compressive strength, low specific weight, improve stiffness and superior energy absorption. Therefore, in this work, a novel material is developed as a reinforcing agent in the aluminum matrix called the Cermet Hollow Sphere (CHS). The CHSs were developed from ceramic powder (SiC) and steel powder (316L) using the powder metallurgy technique. The CHSs have a diameter range of 3 to 9 mm of shell thickness of 0.5 ± 0.1 mm to increase toughness of the cermet. On the other hand, the pure aluminum matrix is replaced with a strong aluminum matrix (LM24), which is commonly used in automotive industries for engine block, cylinder head and transmission case manufacturing due to its excellent die-cast characteristics and strength.

In this work, four categories of foam samples were manufactured for comparative study to identify the best performance, in terms of energy absorption. Then, the foam samples were produced using:

- TiH₂ as a foaming agent.
- LM24/CHS at different mixing ratios of the CHS.
- Hybrid foam from LM24/Al₂O₃/SHS at different ratios of the Al₂O₃ and SHS.
- LM24 Foam reinforced with CHS at different weight ratios of the CHS.

Furthermore, the detailed manufacturing process of the CHS, SHS, matrix and composite metal foam samples, as well as testing and characterization are discussed in the study. Among the developed foam samples, the LM24/CHS foam has shown superior mechanical properties such as high strength-to-weight ratio, compressive strength and higher energy absorption, which are the essential parameters of any metal foams for impact applications.

अमूर्त

धातु फोम एक सिंथेटिक सेलुलर सामग्री है जिसका उपयोग विभिन्न वाणिज्यिक और सैन्य अनुप्रयोगों के लिए किया जा रहा है। उदाहरण के लिए, टाइटेनियम और मैग्नीशियम फोम अपनी जैव-रासायनिकता के कारण हड्डी प्रत्यारोपण के रूप में काम करते हैं। दूसरी तरफ, एल्यूमीनियम फोम दीवार निर्माण, ध्वनि, सदमे या कंपन भिगोना, थर्मल इन्सुलेशन, हीट एक्सचेंजर्स, ऑटोमोटिव बॉडी पार्ट्स, टकराव/क्रश सुरक्षा के निर्माण के लिए लागू हो सकता है। इसके अतिरिक्त, BLAST शमन और बैलिस्टिक संरक्षण अनुप्रयोगों जैसे सैन्य उत्पाद। जबकि स्टील फोम का अध्ययन बैलिस्टिक सुरक्षा अनुप्रयोगों के लिए किया गया था, वर्तमान में ब्लास्ट शमन और टकराव संरक्षण के लिए उपयोग में आम धातु फोम उनके उच्च शक्ति-से-वजन अनुपात और संक्षारण प्रतिरोध के कारण एल्यूमीनियम फोम हैं। हालांकि, TIH2 पाउडर जैसे फोमिंग एजेंटों का उपयोग करके उत्पादित एल्यूमीनियम और स्टील फोम से जुड़ी सीमा उनका कम शक्ति-से-वजन अनुपात था, जो उच्च ऊर्जा अवशोषण क्षमता की वर्तमान आवश्यकता को पूरा करने में असमर्थ था। इसके लिए, शोधकर्ताओं ने एल्यूमीनियम मैट्रिक्स में छिद्र बनाने के लिए अंतरिक्ष धारकों का उपयोग करने की कोशिश की। हाल ही में किए गए अध्ययनों में से एक ने फोम की संपीड़ित शक्ति में सुधार करने के लिए एल्यूमीनियम मैट्रिक्स में सुदृढीकरण के रूप में स्टेनलेस स्टील खोखले गोले (एसएचएस) और सिरैमिक खोखले क्षेत्रों का उपयोग किया। इसके अलावा, एक अन्य अध्ययन में, सिरैमिक खोखले गोले को एक स्टील पाउडर परत के साथ स्तरित किया गया था, स्टील के सिंटरिंग तापमान पर पाप किया गया था और एल्यूमीनियम मैट्रिक्स फोम की संपीड़ित शक्ति और विरूपण तनाव में सुधार के लिए सुदृढीकरण के रूप में उपयोग किया गया था और इसलिए एल्यूमीनियम फोम की तुलना में उच्च ऊर्जा अवशोषण क्षमता थी। हालांकि, इन फोमों में अभी भी अवर यांत्रिक गुण हैं। संपीड़ित शक्ति, छिद्र और विरूपण तनाव को बढ़ाने के लिए एक नए अध्ययन की आवश्यकता थी क्योंकि ये पैरामीटर सीधे उच्च ऊर्जा अवशोषण संपत्ति से संबंधित हैं। इसलिए, मैट्रिक्स सामग्री को एल्यूमीनियम से एल्यूमीनियम-मिश्र धातु में बदल दिया जाना चाहिए, इसी तरह सिरैमिक और स्टील के खोखले क्षेत्रों के गुणों को बंद-सेल फोम के उच्च प्रदर्शन के लिए बेहतर बनाने की आवश्यकता है।

आमतौर पर, इनपुट सामग्री के गुणों को नियंत्रित करके, धातु फोम के मुख्य गुण, जैसे कि इसकी हल्की, उच्च संपीड़ित शक्ति, कम विशिष्ट वजन, कठोरता और बेहतर ऊर्जा अवशोषण में सुधार। इसलिए, इस काम में, एक उपन्यास सामग्री को एल्यूमीनियम मैट्रिक्स में एक मजबूत एजेंट के रूप में विकसित किया गया है जिसे सेमेंट खोखले क्षेत्र (सीएचएस) कहा जाता है। CHSS को पाउडर धातुकर्म तकनीक का उपयोग करके सिरैमिक पाउडर (SIC) और स्टील पाउडर (316L) से विकसित किया गया था। CHSS में Cermet की कूटता को बढ़ाने के लिए 0.5 mm 0.1 मिमी की शेल मोटाई की 3 से 9 मिमी की व्यास रेंज है। दूसरी ओर, शुद्ध एल्यूमीनियम मैट्रिक्स को एक मजबूत एल्यूमीनियम मैट्रिक्स (LM24) के साथ बदल दिया जाता है, जो आमतौर पर इंजन ब्लॉक, सिलेंडर हेड और ट्रांसमिशन केस निर्माण के लिए ऑटोमोटिव उद्योगों में उपयोग किया जाता है जो इसकी उत्कृष्ट ड्राई-कास्ट विशेषताओं और शक्ति के कारण होता है।

इस काम में, ऊर्जा अवशोषण के संदर्भ में, सबसे अच्छे प्रदर्शन की पहचान करने के लिए तुलनात्मक अध्ययन के लिए फोम नमूनों की चार श्रेणियों का निर्माण किया गया था। फिर, फोम के नमूनों का उपयोग करके उत्पादन किया गया:

- TIH2 एक फोमिंग एजेंट के रूप में।
- Ch के अलग-अलग मिश्रण अनुपात में □ LM24/CHS।
- Al_2O_3 और SHS के विभिन्न अनुपातों में LM24/ Al_2O_3 /SHS से Hybrid फोम।
- LM24 फोम सीएचएस के विभिन्न वजन अनुपात में सीएचएस के साथ प्रबलित।

इसके अलावा, सीएचएस, एसएचएस, मैट्रिक्स और मिश्रित धातु फोम नमूनों की विस्तृत निर्माण प्रक्रिया, साथ ही साथ अध्ययन में परीक्षण और लक्षण वर्णन पर चर्चा की गई है। विकसित फोम नमूनों में, LM24/CHS फोम ने उच्च शक्ति-से-वजन अनुपात, संपीड़ित शक्ति और उच्च ऊर्जा अवशोषण जैसे बेहतर यांत्रिक गुणों को दिखाया है, जो प्रभाव अनुप्रयोगों के लिए किसी भी धातु फोम के आवश्यक पैरामीटर हैं।

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LIST OF ABBREVIATIONS

CHS	Cermet Hollow Spheres
CMF	Composite Metal Foam
EPS	Expanded Polystyrene Spheres
FBR	Fluidized Bed Reactor
FML	Fiber Metal Laminate
HCS	Hollow Carbon Spheres
HRTEM	High Resolution Transmission Electron Microscope
IED	Improvised Explosive Device
IFAM	Institute for Manufacturing Technology and Advanced Materials
MMC	Metal Matrix Composite
NATO	North Atlantic Treaty Organization
NIJ	National Institute of Justice
PVA	Polyvinyl Alcohol
RHA	Rolled Homogenous Armor
SAED	Selected Area of Electron Dispersion
SHS	Steel Hollow Spheres
UHMWPE	Ultra High Molecular Weight Polyethylene
Wt.%	Weight Fraction